Excitonic condensation, quadriexcitons and pairing gap in a symmetric electron-hole bilayer with valley degeneracy

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The realization of systems of spatially separated electrons and holes, in the search of the equilibrium excitonic condensate foreseen by [1], has gone on for more than two decades, but so far the condensate has eluded experimental detection [2], in the absence of a magnetic field. It has been recently suggested that a substantial enhancement of the electron-hole attraction, to favour the condensate, could be obtained in coupled graphene bilayers [3], systems that have a quadratic energy dispersion on a wide density range and a twofold valley degeneracy in each bilayer.
We thus embarked in extensive QMC simulations of an electron-hole bilayer with mass symmetry and twofold valley degeneracy (in each layer), to partially mimic the coupled graphene bilayers proposed in [3]. An additional goal of our study is to provide benchmark results for the electron-hole bilayer, investigating the qualitative and quantitative effects of the valley degeneracy, inferred by comparison with the conventional electron-hole bilayer possessing only spin degeneracy [4].
We have studied systems of 168 particles, for in-layer densities corresponding to $1 \leq r_s \leq 8$ and inter-layer distances $1 \leq d/a_B \leq 4$. We find an excitonic condensate for $r_s \gtrsim 1$ at intermediate distances, whereas a quadriexciton fluid [5] and a plasma fluid are stable respectively at smaller and larger distances. The region of stability of the excitonic condensate is significantly shrunk with respect to the system without valley degeneracy [4]. Moreover, we observe for the first time the formation of quadriexcitons, first predicted by Wang and Kittel [5] 45 years ago. Currently, we are estimating excitation energies and the pairing gap in the excitonic condensate.
The first experiments[6] on coupled graphene bilayers in zero magnetic field have found no evidence of excitonic condensation, at variance with the very recent mesaurement [7] on the same system in the quantum Hall regime.

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